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CloudSat Anomaly Recovery and Operational Lessons Learned

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Outline

- Introduction
  - …CloudSat mission, Science value, Spacecraft System
- Battery Degradation / Anomaly
  - …History, Under Voltage (UV), Emergency Mode
- Characterizing the Anomaly
  - …Exit the Afternoon Constellation, Escaping Emergency Mode
- Developing new flight modes
  - …Sun Point Spin, Momentum Bias Point, Daylight Only Operations
- Daylight Only Operations (DO-Op)
  - …The new normal
- Lessons Learned
  - …Keys to success, Team takeaways

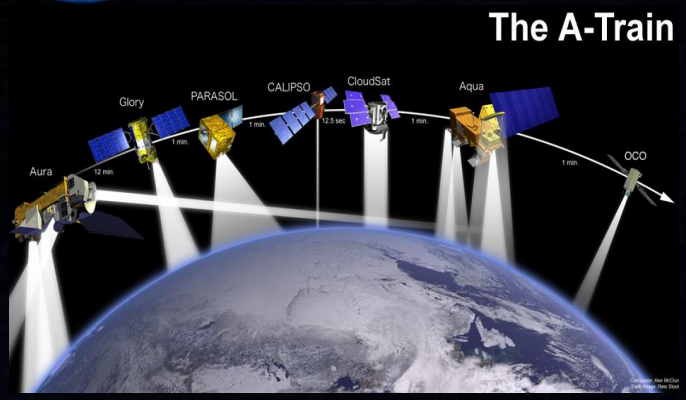
Introduction (1/2)

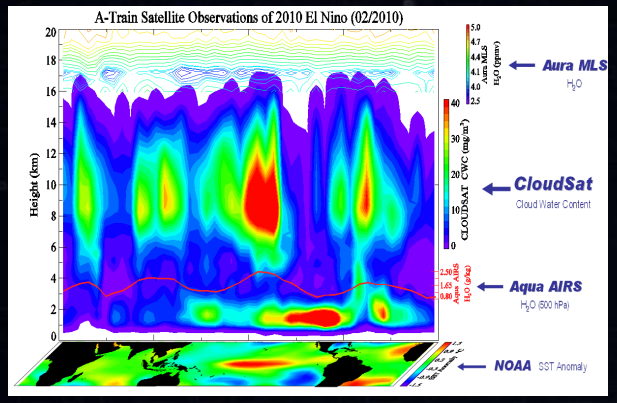
…About the CloudSat mission

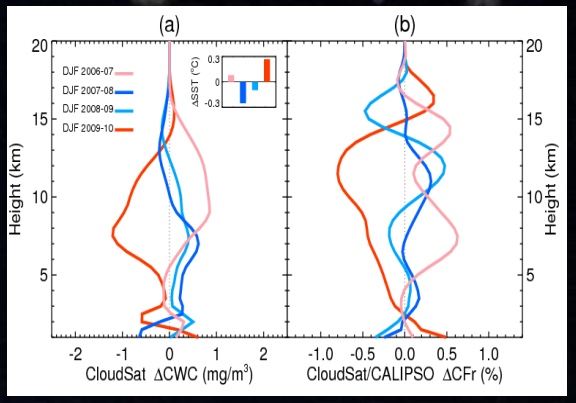
- Launched in 2006, part of NASA Earth System Science Pathfinder Program
- Unique millimeter wavelength cloud profiling radar (CPR)
  - 1000+ times more sensitive than any ground based radar
  - Mission goal: Build first global survey of vertical structures, profiles of condensed water, ice in clouds
- Designed for 22-month life; 6+ yrs to date

Introduction (2/3)

…Science value of CloudSat







- Understanding of how Earth's clouds influence climate change
- Determine relationships between variability of clouds with key environmental factors
  - Characterize changes across seasons and on a decadal time scale
- Rich synergy with A-Train observations extending mission reach
  - Example: 3-D structure of cloud response to multiple El Ninos

Introduction (3/3)

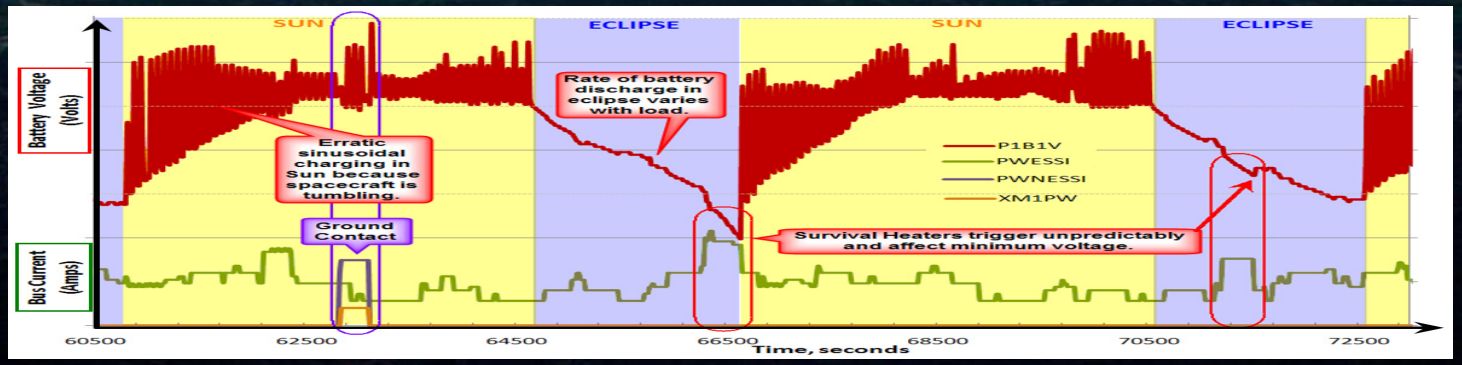
…Systems Architecture

- Power
  - Direct energy transfer power architecture
  - Two solar arrays: 1000 W of power to recharge 40 Amp-hr battery
- Thermal
  - Primarily passive, but contains thermostatic & manual control heaters
  - Critical 'survival' heaters cannot be externally disabled
- Fault protection
  - If system discharges past certain level: Under-Voltage fault
  - Power buses shed to keep power to essential components
  - Highly flexible: Key to recovery
- ADCS
  - Three axis control: torque rods, reaction wheels, thrusters

Battery Anomaly

…Emergency Mode

- 2009: Battery shows signs of aging: Soft-short
- 2010: Ground contacts restricted to sunlight only: CPR collections continue in eclipse
- 17 Apr 2011: UV levels trip, CloudSat descends to Emergency Mode
  - Stable spin up around X-axis to maintain positive power profile
  - With survival heaters on: Battery able to support 10% of previous energy
- Eclipse battery charge constantly drained by survival heater activation
  - To even consider recovery, additional load capacity needed



Characterizing the anomaly (1/3)

…Understanding the problem

- Battery victim of *diffusion limiting current*
  - Sudden drop in voltage when diffusion limit reached
- Recursive problem: Manual charge control insufficient
  - Survival heater turns on in eclipse -> Current limit exceeded -> UV fault trips -> Charge level reduced to default
  - With inability to support loads: Primary heaters shed -> Battery temps drop -> Reduced battery capacity -> More frequent UV fault trips -> More frequent heater trips
- Recovery Step 1:
  - Modify redundant power control system to reduce fault thresholds while maintaining high charge rate

Characterizing the anomaly (2/3)

…Exit from Afternoon Constellation

- Risk to A-Train (especially AQUA) from control box drift
- Complications:
  - Variation of Emergency Mode spin rate : Thruster fire to place S/C in a stable spin rate for power capture
    > Risk: Causes small unpredictable ΔV
  - SCC needed to stay on through eclipse for maneuver commanding
- Recovery Step 2: Component pre-heating strategy
  - During one critical commanding contact: All commands transmitted to turn select manual heaters on, recover control, execute maneuver -- successful orbit lower

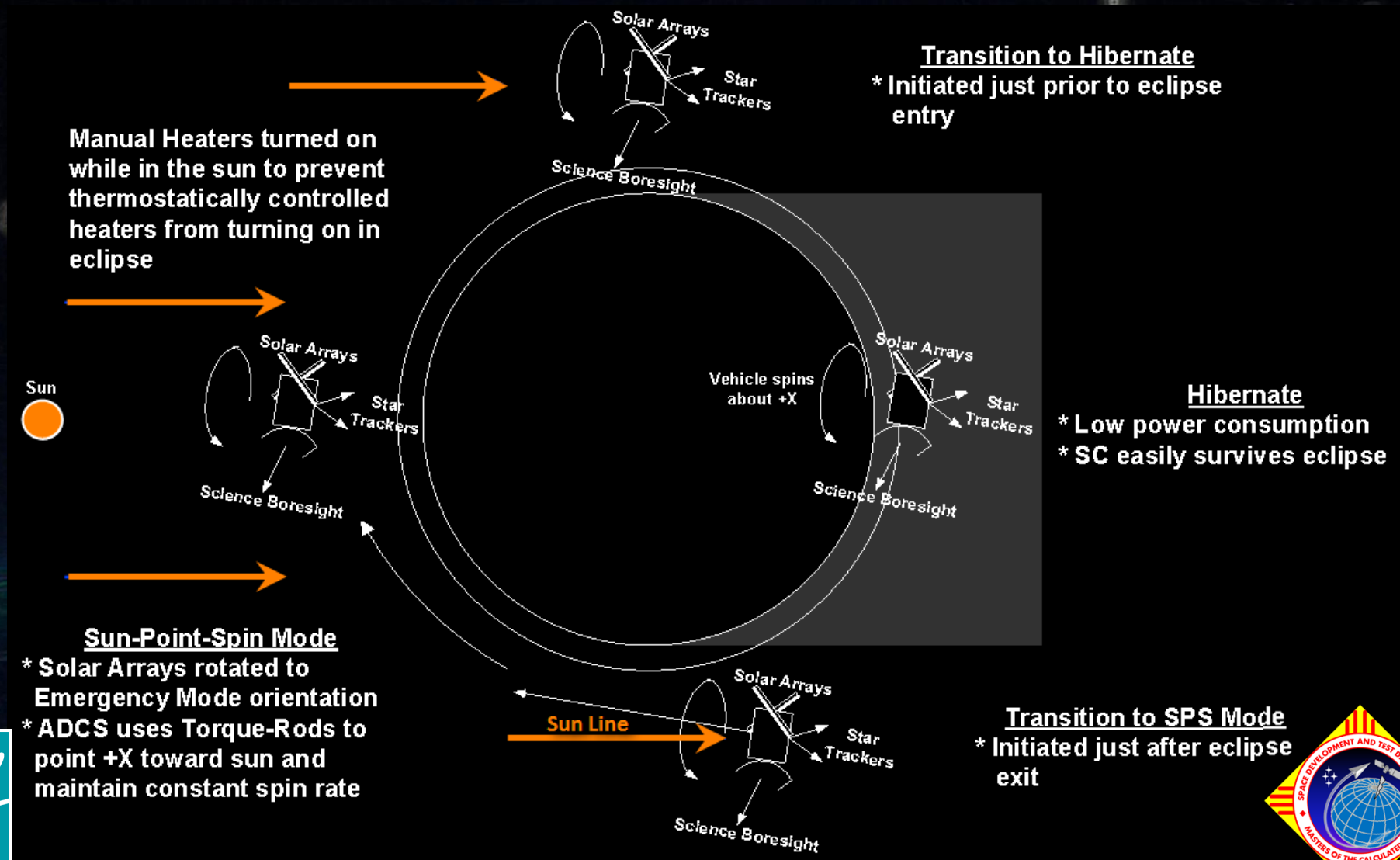
Characterizing the anomaly (3/3)

…Way forward revealed!

- Pre-heating with manual heaters could keep survival heaters off, avoid UV faults
- CONS:
  - Heater cycling needed every eclipse exit & entry
  - Heater power available only in select spin-to-sun orientations
  - Reaction wheels must be off in eclipse: Without 3-axis control, spacecraft drift could off-point arrays on eclipse exit
- Way forward to Recovery Step 3 clear
  - New flight modes needed without flight software change

Developing new flight modes (1/4)

…Sun Point Spin



Developing new flight modes (2/4)

…Momentum Bias Point Mode

- SPS proved SCC could stay powered, recover ops after exiting eclipse
- Recovery Step 4: Storing momentum in reaction wheels
  - Maintains spin stabilized attitude through eclipse
  - Maneuvers CPR to nadir after eclipse exit
  - Points X-axis & rotates solar arrays to Sun, upon exit
- SPS upgraded to Momentum Bias Point
  - Return to operational capability within reach!
- Recovery Step 5: Adding CPR cycling to sequence

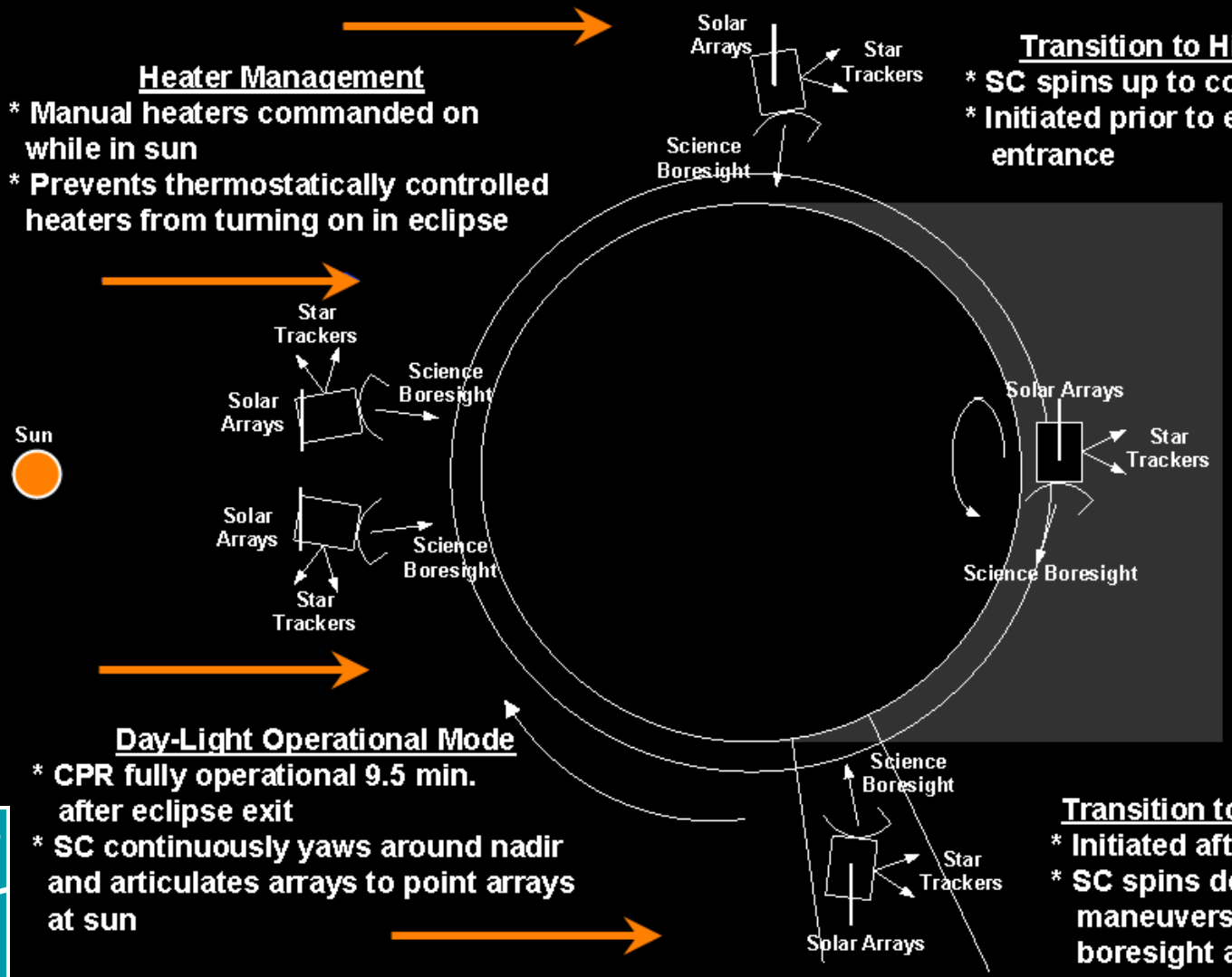
Developing new flight modes (3/4)

…Graduating to Daylight Ops

- Pre-heating strategy developed to raise the CPR temp
  - If CPR survival heaters trigger in eclipse: UV fault
  - Preparatory (PREP) mode needed as preface to Daylight Only Operations (DO-OP)
- Other modes developed to support DO-OP CONOPS:
  - Recovery mode: Uses less heater power than SPS mode
  - COLA mode: Enables short notice orbit lowers, raises
  - ΔV mode: Enables any other designed maneuver burns

Developing new flight modes (4/4)

…Standby, Prep, DO-OP



Daylight Only Operations (DO-Op)

…The new normal

Anomaly lessons learned (1/3)

…Keys to success

- Communication
- Involvement
- Co-Location
- Creativity
- Risk Management
- Flexible assets
  - AFSCN
  - GSA
  - Test Bench
- Veteran Team
- Urgency

Anomaly lessons learned (2/3)

…Team Takeaways

- Understanding
- Scrutiny
- Risk
- Luck
- Staffing
- Mission Assurance

Anomaly lessons learned (3/3)

…Conclusion

- Nov 2011: NASA/JPL declared CloudSat fully operational in DO-OP Mode
- CloudSat collects science data during sunlit portion of orbit, stable spin hibernation in eclipse
- New CONOPS requires constant monitoring of thermal and power profiles, while allowing collection of 54 mins of science data per sunlit orbit
- New flight modes successfully integrated into operations: CloudSat returning to the A-Train!